

INOCULATED GROWTH PROMOTING RHIZOBACTERIA IN SERRANO CHILI PEPPER (*Capsicum annuum* L.) SEEDLINGS UNDER ABIOTIC STRESS CONDITIONS

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ABSTRACT

Mexico is the world's second largest chili pepper producer. Its production requires high amounts of chemical fertilizers, generating environmental problems such as water scarcity and soil salinity. There are alternatives to reduce this problem, one of them is the use of plant growth promoting rhizobacteria. The hypothesis of this work was that by inoculating chili pepper (*Capsicum annuum* L.) seedlings with growth-promoting rhizobacteria, the effects caused by salt and water stress are reduced and their growth is promoted. The objective was to evaluate five bacterial strains with growth-promoting capacity in the production of chili pepper seedlings grown under salt and water stress. A completely randomized experimental design with factorial arrangement (AxB) was used, where factor A (bacterial strain) had five levels (strains of different species), and factor B (substrate moisture content) four levels (100, 75, 50, and 25 %), having 24 treatments with five replicates each, generating 120 experimental units. Moisture was maintained with the application of a NaCl solution in water in all experimental units. Plant height, root length, fresh weight, dry matter, seedling sodium concentration, and the presence of rhizobacteria in the root were evaluated. The rhizobacterium *Acinetobacter johnsonii* showed significant differences with respect to the control without inoculation for the variables plant height with 12.4 cm, root length with 10.6 cm, fresh weight with 1.266 g, and dry matter with 0.394 g; for the concentration of Na⁺ in the plant, the rhizobacterium *ixta gaviniiae* obtained a concentration of 3.60 g of Na⁺ per kg of seedling with respect to the control without inoculation. Therefore, these rhizobacteria can be used as an alternative method to control water and salt stress in chili pepper seedlings and improve their initial development.

Keywords: *Acinetobacter johnsonii*, *Mixta gaviniiae*, salinity, water stress.

INTRODUCTION

Chili pepper (*Capsicum annuum* L.) is one of the most economically important crops within horticulture, with China being the world's leading producer with more than 10.7 million Mg produced, while Mexico ranks second with 1.7 million Mg (FAO, 2020).

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The most cultivated chili pepper varieties in the country are jalapeño, poblano, and serrano, whose management demands high amounts of chemical fertilizers, which translates into high production costs and potential soil contamination (Salazar-Jara and Juárez-López, 2013), causing environmental problems such as water scarcity and soil salinity. Salinity is a limiting environmental component for plant development. Although the original source of salts comes from the primary minerals that form the rocks, the soluble salts in the soil come mostly from the salts dissolved in the irrigation water (Santamaría-César *et al.*, 2004). Chili pepper plants are sensitive to salt stress (Azuma *et al.*, 2010); high salt concentration in soil and water inhibits metabolic processes and affects nutrient uptake.

Seedling production quality is a combination of characteristics such as height, stem diameter, root length (Araméndiz-Tatis *et al.*, 2013), number of leaves, and leaf area (Vidigal *et al.*, 2011), which affect their vigor. A good development free of pests and diseases allows greater adaptability to transplanting, with high water and nutrient absorption capacity (Salusso *et al.*, 2015). Producing high quality and vigorous chili seedlings ensures excellent fruit production under greenhouse conditions (Sarduy *et al.*, 2016).

An alternative method that can help seedling establishment is the use of microorganisms (Kumar *et al.*, 2012), which has been implemented for the benefit of agricultural indicators since ancient times (Bhattacharyya and Jha, 2012). Thus, the effects of different types of abiotic stresses (such as drought, extreme temperatures, salinity, and metal toxicity) are reduced by the application of beneficial microorganisms (Milošević *et al.*, 2012).

Several authors such as Kang *et al.* (2014), Padmavathi *et al.* (2015), and Palmer *et al.* (2018) have used plant growth-promoting rhizobacteria (PGPR) belonging to the genera *Acinetobacter*, *Bacillus*, *Mixta*, among others.

The use of PGPR can lead to multifactorial benefits, such as: phosphate solubilization, production of siderophores, volatile organic compounds (VOCs), and 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase enzyme; as well as biological nitrogen fixation, phytohormone production and regulation, pathogen biocontrol, activation of induced systemic resistance (ISR), among others (Bhattacharyya and Jha, 2012). The PGPR can adapt to diverse environmental scenarios and help mitigate stress conditions in plants.

In situations of drought or salinity, the protective effect of rhizobacteria consists of reducing ethylene production and increasing the concentration of phytohormones such as abscisic acid and auxins; in addition, give protection against reactive oxygen species (ROS), produce compatible solutes, solubilize phosphates, produce exopolysaccharides, and control phytopathogens (Ruppel *et al.*, 2013).

Salazar-Ramirez *et al.* (2021) conducted a study to isolate PGPR from the rhizosphere of candelilla (*Euphorbia antisiphilitica* Zucc.); the isolated rhizobacteria were tested against *Arabidopsis thaliana* in a Petri dish system with Murashige and Skoog (MS) medium to test their growth-promoting and salt stress protection properties.

Based on the results obtained, five rhizobacteria were selected, which stimulated the growth of *Arabidopsis thaliana* under standard and saline conditions. Some of the mechanisms identified were the production of indole-3-acetic acid (IAA), siderophores, phosphate solubilization, and ACC deaminase enzyme activity. These data reveal the potential of candelilla rhizobacteria to promote growth and confer salinity tolerance. Based on the above, the hypothesis of this study was that inoculating serrano chili pepper (*Capsicum annuum* L.) seedlings with growth-promoting rhizobacteria reduces the effects of water stress under salinity conditions and promotes seedling growth. The objective of this study was to evaluate the response of five plant growth-promoting rhizobacteria isolated from the candelilla rhizosphere on the production of serrano chili pepper seedlings, under water stress in saline irrigation conditions.

MATERIALS AND METHODS

Experimental site

The research was carried out during the spring-summer 2020 agricultural cycle at the Biotechnology Laboratory of the Instituto Tecnológico de Torreon (ITT) located at Antigua Carretera Torreon-San Pedro km 7.5, Torreon, Coahuila, Mexico. The predominant climate in this region is semi-desert, with average annual rainfall between 100 and 300 mm, average temperature between 30 and 40 °C in summer, and 8.5 °C in winter.

Plant material

Serrano chili pepper (*Capsicum annuum* L.) seeds were disinfected in 20% chlorine for 5 minutes and washed four times with sterile distilled water.

Inoculum preparation and characteristics of rhizobacteria

The rhizobacteria used in the research were isolated from candelilla rhizosphere (*Euphorbia antisyphilitica* Zucc.) and identified by 16s rRNA gene (Table 1) using the CTAB technique (Doyle and Doyle, 1990) by Salazar-Ramírez *et al.* (2021).

Table 1. Molecular identification of bacteria isolated from candelilla rhizosphere (*Euphorbia antisyphilitica* Zucc.).

ID	Taxon	bp	Identity (%)	Accession number
NFbEcto18	<i>Acinetobacter johnsonii</i>	353	82	NR_164627.1
CASEcto4	<i>Staphylococcus epidermidis</i>	1402	99	NR_036904.1
CASEcto12	<i>Mixta gaviniae</i>	641	99	NR_117305.1
CASEcto13	<i>Staphylococcus epidermidis</i>	1377	95	NR_113957.1
CASEndo10	<i>Bacillus cereus</i>	1398	99	NR_074540.1

Molecular identification using the 16S rRNA gene of rhizobacteria isolated from candelilla (Salazar-Ramírez *et al.*, 2021). ID: identification; bp: DNA base pairs.

The strains had characteristics of salinity tolerance (Table 2), phosphate solubilization, and production of the enzyme ACC deaminase, siderophores and indoleacetic acid (Table 3), which gives them characteristics of plant growth promoters.

The strains were grown in nutrient broth under constant agitation for three days at 28 °C until a concentration of 1×10^8 CFU mL⁻¹ was obtained. Direct inoculation was performed on serrano chili pepper seed with the aforementioned concentration. After four days of growth, they were placed in pots with substrate, and four days later the seedlings were inoculated again with a concentration of 1×10^8 CFU mL⁻¹, to be harvested 50 days after application.

Table 2. Development of rhizobacteria under different NaCl concentrations.

ID Rhizobacteria	Salinity tolerance			
	0.85 M (5 %)	1.7 M (10 %)	2.55 M (15 %)	3.4 M (20 %)
NFbEcto18	+++	++	+	-
CASEcto4	+++	+++	+++	+
CASEcto12	+++	+	+	-
CASEcto13	+++	+++	+++	+
CASEndo10	+++	+++	+++	-

Bacterial growth under different NaCl concentrations (Salazar-Ramírez *et al.*, 2021).
 +++ maximum growth; ++ medium growth; + minimum growth; - no growth.

Table 3. Biochemical characterization of rhizobacteria.

ID Rhizobacteria	Phosphate solubilization (mm)	IAA production (µg mL ⁻¹)	Siderophore production	ACC deaminase activity (µmol α-KB (mg Pr) h ⁻¹)
NFbEcto18	-	14.630	+	0.878
CASEcto4	2.133 ± 0.399	6.429	+	0.457
CASEcto12	2.667 ± 0.900	11.905	+	0.344
CASEcto13	2.933 ± 0.530	5.026	+	0.685
CASEndo10	1.400 ± 0.507	11.984	-	0.157

Results of biochemical characterization of rhizobacterial isolates (Salazar-Ramírez *et al.*, 2021).
 ± Arithmetic means, standard deviation of triplicate experiments; + development; - no development; AIA: indole-3-acetic acid. The activity of the enzyme 1-aminocyclopropane-1-carboxylic acid deaminase (ACC deaminase) is measured in µmol of α-ketobutyrate (KB) mg⁻¹ Pr (protein) h⁻¹.

Substrate and irrigation used

The substrate used for the growth of serrano chili pepper seedlings consisted of a mixture of peat moss, perlite, and vermiculite (2:1:1 ratio), which was sterilized in an autoclave at 124.1 kPa pressure for 2 h. Pots of 1.3 L capacity were filled with this substrate. Water with an electrical conductivity (CE) of 2.5 dS m⁻¹ was used, which is

considered highly saline (1.5 to 3.0 dS m⁻¹), according to the classification of irrigation water, which helps to generate salt stress.

Irrigation was applied based on the usable humidity (HA) of the substrate, managing 4 levels (100, 75, 50, and 25 %), in order to obtain different irrigation regimes and generate a water deficit.

The irrigation lamina to be applied for each HA level was obtained from the moisture retention curve according to the following equation, also reported by Borges-Gómez *et al.* (2010):

$$Va - (CC - PMP) Da Vs$$

where Va is the volume of water to be applied (L), CC is the water content at field capacity (%), PMP is the water content at permanent wilting point (%), Da is the bulk density (g cm⁻³), and Vs is the volume of the substrate (L).

Variables evaluated

Seedling height

This variable was measured every third day before each application of the treatments, using a vernier. The data referred to this variable are expressed in centimeters (cm).

Root length

When the plant was sampled destructively, excess substrate was removed from the root by washing with water. When it was clean, it was measured with a tape measure.

Fresh weight of leaves, stem, and root

It was quantified only once at the end of the experimental work. A VE-500 digital analytical scale (Velab, USA) was used. The results obtained are expressed in grams (g).

Dry weight of leaves, stems, and roots (dry matter)

It was quantified at the end of the experimental work. The previously weighed plant material was left for 72 hours in a drying oven at a temperature of 65 °C, and its weight was measured again. The results for this variable are expressed in grams (g).

Sodium concentration in seedlings

For the determination of sodium (Na⁺) content, 50-day-old serrano chili pepper seedlings were taken from each of the treatments evaluated, subjected to dry digestion and analyzed in a GBC Explora atomic absorption spectrophotometer (GBC Scientific Equipment, Melbourne, Australia).

Microbiological analysis (CFU)

The microbiological analysis of the root part of the seedling was carried out with a wash in distilled water, from which serial dilutions were made (-1, -2 and -3) to

proceed to sowing in Petri dishes with LB medium. Only -3 dilutions were seeded. The boxes were incubated for 72 h, for which the formula of Colony Forming Units per gram of root was used according to the serial dilution procedure (CFU g⁻¹ in each substrate).

Experimental design and statistical analysis

An A x B factorial arrangement was used, where factor "A" comprises the five rhizobacteria used (NFbEcto18, CASEcto4, CASEcto12, CASEcto13, CASEcto10) and a control without inoculation, and factor "B" the four irrigation regimes (100, 75, 50, and 25 %), under a completely randomized design. This gave a total of 24 treatments with five replicates each, generating 120 experimental units. The data of the variables were subjected to an analysis of variance and the means were compared by the Tukey test ($p \leq 0.05$) in the statistical package SAS (Statistical Analysis System) version 9.1. The graphs were prepared in GraphPad Prism 6.

RESULTS AND DISCUSSION

Effectiveness of rhizobacteria in growth promotion

Statistical analysis for the evaluation of the effect of rhizobacteria on the growth promotion of serrano chili pepper seedlings, fifty days after sowing (das), showed significant differences ($p \leq 0.05$) among treatments. For the plant height variable (Table 4), the strain identified as *Acinetobacter johnsonii* NFbEcto18 obtained an average of 9.975 cm; for the root length variable, its average was 8.150 cm, thus showing significant statistical differences compared to the control without inoculation.

Table 4. Effect of rhizobacteria on growth promotion of serrano chili pepper (*Capsicum annum* L.) seedlings.

Rhizobacteria	Plant height (cm)	Root length (cm)	Fresh weight (g)	Dry matter (g)
Control	3.6 e	5.325 c	0.232 c	0.024 c
NFbEcto18	9.975 a	8.15 a	1.018 a	0.067 b
CASEcto4	6.375 c	4.675 d	0.16 d	0.026 c
CASEcto12	9.05 b	6.1 b	1.045 a	0.079 a
CASEcto13	4.9 d	6.3 b	0.219 cd	0.023 c
CASEcto10	5.825 c	6.2 b	0.247 c	0.050 b

*Means with different letters in column represent statistical differences (Tukey, $p \leq 0.05$).

In the variables of fresh weight with 1.045 g and dry matter with 0.079 g, the rhizobacterium *Mixta gaviniae* CASEcto12 showed significant statistical differences compared to the control without inoculation.

The bacterial strains used in this research that showed the best results have been documented in different crops, as reported by Kang *et al.* (2014), where the application

of rhizobacteria of the genus *Acinetobacter* on cucumber seedlings at 41 das showed growth promotion in plant height (27.47 cm), fresh weight (6.28 g), and dry matter (0.73 g). It has also been used in alfalfa, oats (Li *et al.*, 2020), beets (Shi *et al.*, 2011), tomato, and sweet bell pepper (Padmavathi *et al.*, 2015). For the serrano chili pepper seedlings used in this research, 1.018 g fresh weight and 0.067 g dry matter were reported for *Acinetobacter*, which presented significant difference with respect to the control without inoculation.

The rhizobacterium *Mixta* was proposed as a novel genus in 2018, based on a genomic study of members of the genus *Pantoea*. The first four species placed in this genus were reclassified from the genus *Pantoea*. The genus name *Mixta* refers to the “mixed lifestyles of the species in the genus” (Palmer *et al.*, 2018). Therefore, there are not many studies that refer to the growth promotion efficacy of the rhizobacterium *Mixta gaviniae*, but there are for the genus *Pantoea*. A study by Kim *et al.* (2012) proved the effect of the genus *Pantoea* in increasing plant height, number of leaves, and fresh weight of cucumber, tomato and chili pepper plants by up to 123 %, compared to the uninoculated control.

In the results reported by Salazar-Ramírez *et al.* (2021), the rhizobacterium *Mixta gaviniae* has diverse capacities, such as salinity tolerance up to 15 % (2.55 M), production of the enzyme ACC deaminase, phosphate solubilization, and production of siderophores and indoleacetic acid. All these features promote growth by diffusible and volatile compounds in *Arabidopsis thaliana*, which suggests considering them as PGPR. In this study, the rhizobacterium *Mixta gaviniae* reported a plant height of 9.05 cm and a root length of 6.1 cm, showing significant differences compared to the control without inoculation. Therefore, our results add one more culture in which *Acinetobacter* and *Mixta gaviniae* rhizobacteria have been evaluated as growth promoters, obtaining favorable results for the cultivation of serrano chili pepper.

The former demonstrates the relevance of the use of PGPR in the development of seedlings of agricultural interest, since they allow the production of better developed seedlings with greater possibilities of surviving transplanting in the field.

Effectiveness of irrigation regimes on the growth of serrano chili pepper seedlings.

Based on the percentage of moisture loss and the variables evaluated, the best irrigation regime to favor plant height was 100% (224 mL); for root length and fresh weight, the 25 % irrigation (56 mL) was the best, and for dry matter, the 50 % irrigation (112 mL) showed the best results (Table 5). The 25% irrigation regime fulfills one of the stated objectives, which shows that even in water deficit, it is possible to promote the growth of chili seedlings in an adequate manner.

According to Bacallao and Fundora (2014), water deficit affects every aspect of plant growth, such as anatomy, morphology, physiology, and biochemistry. Among the most obvious general effects of water stress are germination failure, reduction in plant height, leaf area, and crop yield.

The water used for irrigation was managed with an electrical conductivity of 2.5 dS m⁻¹, considered highly saline. Chili pepper is moderately tolerant to salinity, given that

Table 5. Effect of irrigation regimes on the growth of serrano chili pepper (*Capsicum annum* L.) seedlings.

Irrigation	Plant height (cm)	Root length (cm)	Fresh weight (g)	Dry matter (g)
Irrigation 100 %	6.986 a	6.071 b	0.478 a	0.045 b
Irrigation 75 %	6.7 ab	5.786 b	0.406 b	0.030 b
Irrigation 50 %	6.3 bc	5.929 b	0.487 a	0.053 a
Irrigation 25 %	6.157 c	6.786 a	0.487 a	0.039 b

*Means with different letters per column present statistical differences (Tukey, $p \leq 0.05$).

from the use of water with an electrical conductivity of 2 dS m^{-1} , biomass production is affected (Queiroz Lopes *et al.*, 2019).

Effectiveness of the interaction between rhizobacteria and irrigation regimes

The rhizobacterium *Acinetobacter johnsonii* NFbEcto18 with the 25% irrigation regime (56 mL) obtained significant differences with respect to the control without inoculation in the variables of plant height, fresh weight, and dry matter. A bacterial strain was found that promotes growth and at the same time protects against water and salt stress (Table 6 and 7), fulfilling the objective of this work.

Most of the soluble salts in the soil come from irrigation water (Santamaría-César *et al.*, 2004), hence the relevance of irrigating with a NaCl-added water solution from the beginning of germination in this research.

According to what was reported by Kang *et al.* (2014), when using rhizobacteria of the genus *Acinetobacter* in cucumber seedlings subjected to salt stress by adding NaCl to the irrigation water, 21 days after sprouting, a fresh weight of 27.88 g was obtained, and dry matter of 6.96 g, presenting significant differences with respect to the control without inoculation.

Table 6. Effect of the interaction between rhizobacteria and irrigation regimes on growth promotion in plant height and root length of serrano chili pepper (*Capsicum annum* L.) seedlings.

Rhizobacteria	Plant height (cm)				Root length (cm)			
	Irrigation				Irrigation			
	100 %	75 %	50 %	25 %	100 %	75 %	50 %	25 %
Control	4.5jk	3.4k	3.1k	3.4k	5.7hij	4.0lm	6.1ghi	5.5ijk
NFbEcto18	8.8de	8.2ef	10.5bc	12.4a	10.6a	7.7cd	7.2de	7.1de
CASEcto4	9.5cd	7.8efg	4.8k	3.4d	3.5m	4.8klm	4.8klm	5.6hij
CASEcto12	11.5ab	9.6cd	9.8cd	5.3j	5.9ghij	7.0def	6.3fgh	5.2jkl
CASEcto13	4.9kj	5.2j	4.1jk	5.4ij	4.6klm	4.7klm	7.6cd	8.3bc
CASEndo10	5.1jk	7.2fgh	4.6c	6.4hi	6.1ghi	6.6efg	4.8klm	7.3de

*Means with different letters per column present statistical differences (Tukey, $p \leq 0.05$).

Table 7. Effect of the interaction between rhizobacteria and irrigation regimes on growth promotion in fresh weight and dry matter of serrano chili pepper (*Capsicum annum* L.) seedlings.

Rhizobacteria	Fresh weight (g)				Dry matter (g)			
	Irrigation				Irrigation			
	100 %	75 %	50 %	25 %	100 %	75 %	50 %	25 %
Control	0.228ijkl	0.234hijk	0.220ijkl	0.246ghij	0.047kl	0.086hij	0.130efg	0.021mn
NFbEcto18	0.877cd	0.845d	1.082b	1.266a	0.239c	0.128efg	0.284b	0.394a
CASEcto4	0.152jkl	0.134kl	0.190jkl	0.163d	0.020mn	0.058jkl	0.039lm	0.094ghi
CASEcto12	1.248a	0.896cd	1.083b	0.953c	0.395a	0.192d	0.287b	0.265bc
CASEcto13	0.140kl	0.190jkl	0.318efgh	0.226ijkl	0.017n	0.024mn	0.133efg	0.011n
CASEndo10	0.289fghi	0.328efg	0.156jkl	0.215ijkl	0.037lm	0.113fgh	0.097ghi	0.086hij

*Means with different letters per column present statistical differences (Tukey, $p \leq 0.05$).

In the results obtained in this research, serrano chili pepper seedlings inoculated with *Acinetobacter* obtained 1.266 g of fresh weight and 0.394 g of dry matter, showing significant differences with respect to the control without inoculation.

Sodium content in seedlings

For the variable of Na⁺ concentration in seedling, the strains identified as *Acinetobacter johnsonii* NFbEcto18 and *Mixta gaviniae* CASEcto12 obtained on average a concentration of 4.53 and 3.60 g Na⁺ kg plant⁻¹, respectively, for each of the different irrigation regimes (Figure 1).

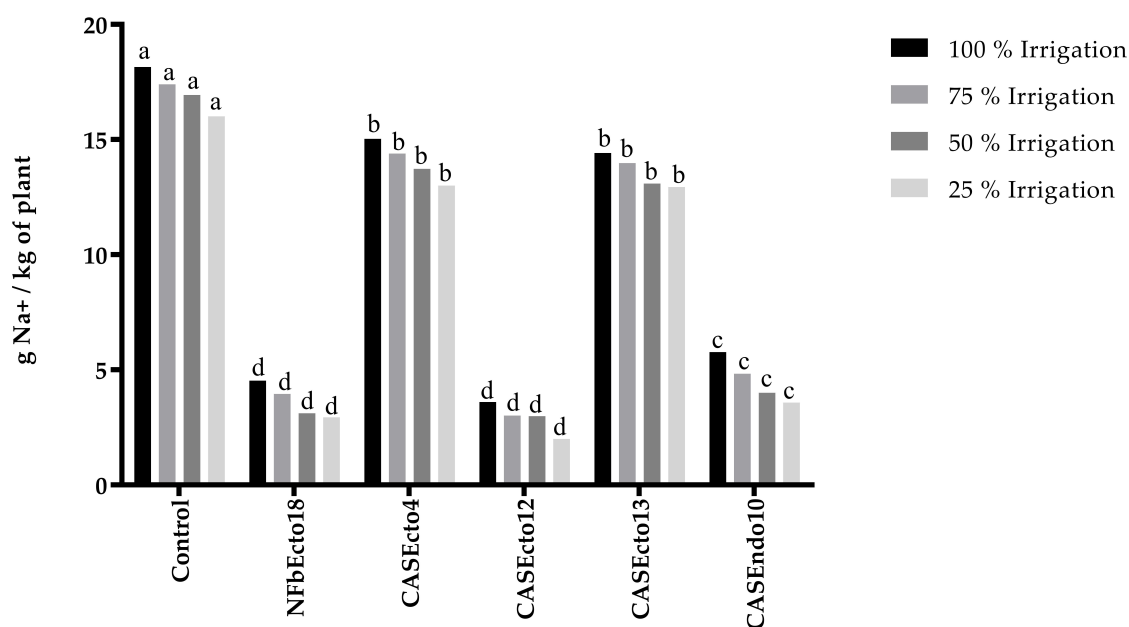


Figure 1. Concentration of Na⁺ in serrano chili pepper (*Capsicum annum* L.) seedlings 50 days after sowing (das). Different letters between each group of columns indicate significant statistical difference (Tukey; $p \leq 0.05$).

This shows that these two strains give protection to the seedling, decreasing the Na⁺ concentration four to six times compared to the uninoculated control.

The reduction in plant growth and yield is largely caused by salt stress (Na⁺), which in turn causes a reduction in water absorption by plants due to the osmotic effect and toxicity of salt. Among the alterations caused are ion imbalance and other metabolic disorders (Hussain *et al.*, 2008; Karlidag *et al.*, 2013).

There are reports where treatments with PGPR possessing the ACC deaminase enzyme have shown to reduce stress levels and confer salinity tolerance in crops grown on media with high salt concentrations (Saharan and Nehra, 2011; Gontia-Mishra *et al.*, 2014; Ali *et al.*, 2014). The rhizobacterium *Acinetobacter johnsonii* used in this research has this characteristic, producing the enzyme at a concentration of 0.878 $\mu\text{mol } \alpha\text{-KB mg}^{-1} \text{ Pr h}^{-1}$ (Table 3), so this behavior can be attributed to it.

Microbiological analysis

In the microbiological counts, no significant statistical differences were found between strains or between irrigation regimes. However, an average development between 1.2×10^5 and 1.5×10^5 CFU g⁻¹ of root was observed in all samples (Figure 2).

Performing the CFU analysis gives us a reference to observe the microbiological behavior and know if any positive or negative response can be attributed to the bacterial strains. In this case, from the results obtained, a positive response to plant growth stimulation is attributed to these rhizobacteria being present in the root.

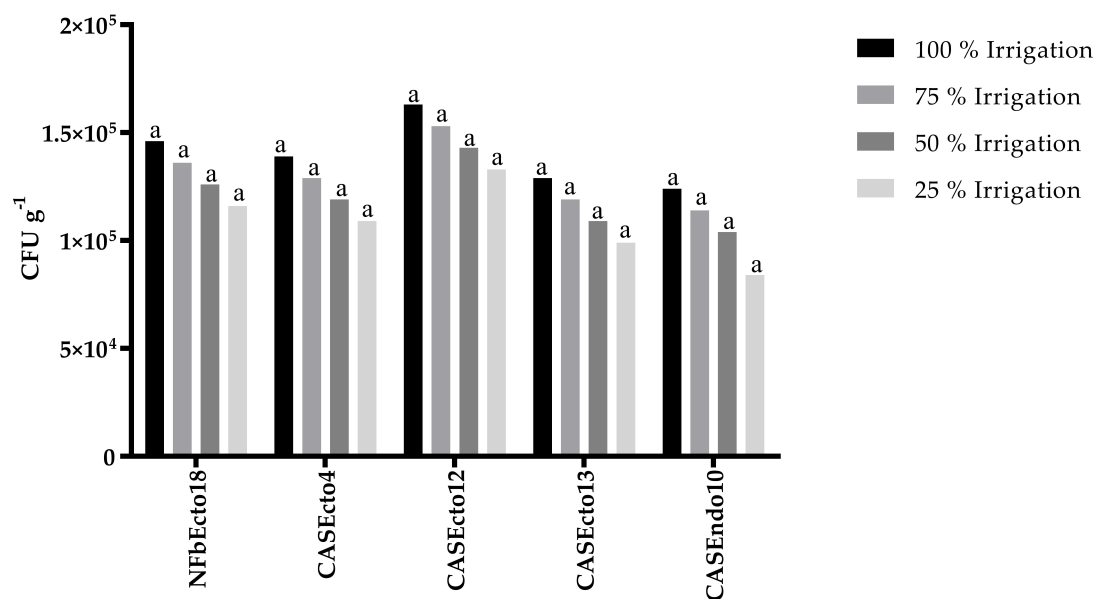


Figure 2. Comparison of means of Colony Forming Units (CFU) per g of root 50 days after sowing (das) serrano chili pepper (*Capsicum annum* L.) seedlings.

CONCLUSIONS

The use of growth-promoting rhizobacteria is effective in promoting the growth of serrano chili pepper seedlings. The strains *Acinetobacter johnsonii* NFbEcto18 and *Mixta gaviniae* CASEcto12 promoted greater height, higher fresh weight, and dry matter in seedlings, as well as reduced the effects of high Na⁺ concentration, so they can be used under salinity stress conditions.

The rhizobacterium *Acinetobacter johnsonii* NFbEcto18 can be used under water stress conditions, since its results with 25% irrigation were favorable. *Mixta gaviniae* CASEcto12 has few records as a growth promoter; therefore, the results of this study constitute an important contribution for this species.

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REFERENCES

- Ali S, Charles TC, Glick BR. 2014. Amelioration of high salinity stress damage by plant growth promoting bacterial endophytes that contain ACC deaminase. *Plant Physiology and Biochemistry* 80: 160–167. <https://doi.org/10.1016/j.plaphy.2014.04.003>
- Araméndiz-Tatis H, Cardona-Ayala C, Correa-Álvarez E. 2013. Efecto de diferentes sustratos en la calidad de plántulas de berenjena (*Solanum melongena* L.). *Revista Colombiana de Ciencias Hortícolas* 7 (1): 55–61. <https://doi.org/10.17584/rcch.2013v7i1.2035>
- Azuma R, Ito N, Nakayama N, Suwa R, Nguyen NT, Larrinaga-Mayoral JA, Esaka M, Fujiyama H, Saneoka H. 2010. Fruits are more sensitive to salinity than leaves and stems in pepper plants (*Capsicum annuum* L.). *Scientia Horticulturae* 125 (3): 171–178.
- Bacallao MF, Fundora LB. 2014. Tolerancia a estrés por déficit hídrico en tomate (*Solanum lycopersicum* L.). *Cultivos Tropicales* 35 (3): 70–88.
- Bhattacharyya PN, Jha DK. 2012. Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. *World Journal of Microbiology and Biotechnology* 28 (4): 1327–1350. <https://doi.org/10.1007/s11274-011-0979-9>
- Borges-Gómez L, Cervantes-Cárdenas L, Ruiz-Novelo J, Soria-Fregoso M, Reyes-Oregel V, Villanueva-Couoh E. 2010. Capsaicinoides en chile habanero (*Capsicum chinense* Jacq.) bajo diferentes condiciones de humedad y nutrición. *Terra Latinoamericana* 28 (1): 35–41.
- Doyle JJ, Doyle JL. 1990. Isolation of plant DNA from fresh tissue. *Focus* 12: 13–15.
- FAO (Organización de las Naciones Unidas para la Alimentación y la Agricultura). 2020. FAOSTAT. Cultivos. Organización de las Naciones Unidas para la Alimentación y la Agricultura. Roma, Italia. <https://www.fao.org/faostat/es/#home> (Recuperado: noviembre 2021).
- Gontia-Mishra I, Sasidharan S, Tiwari S. 2014. Recent developments in use of 1-aminocyclopropane-1-carboxylate (ACC) deaminase for conferring tolerance to biotic and abiotic stress. *Biotechnology Letters* 36 (5): 889–898. <https://doi.org/10.1007/s10529-014-1458-9>
- Hussain K, Ashraf M, Ashraf MY. 2008. Relationship between growth and ion relation in pearl millet (*Pennisetum glaucum* (L.) R. Br.) at different growth stages under salt stress. *African Journal of Plant Sciences* 2 (3): 23–27.
- Kang SM, Khan AL, Waqas M, You YH, Kim JH, Kim JG, Hamayun M, Lee IJ. 2014. Plant growth promoting rhizobacteria reduce adverse effects of salinity and osmotic stress by regulating phytohormones and antioxidants in *Cucumis sativus*. *Journal of Plant Interactions* 9 (1): 673–682. <https://doi.org/10.1080/17429145.2014.894587>

- Karlıdag H, Yildirim E, Turan M, Pehlivan M, Donmez F. 2013. Plant growth-promoting rhizobacteria mitigate deleterious effects of salt stress on strawberry plants (*Fragaria ×ananassa*). HortScience 48 (5): 563–567. <https://doi.org/10.21273/hortsci.48.5.563>
- Kim SN, Cho WK, Kim WI, Jee HJ, Park CS. 2012. Growth promotion of pepper plants by *Pantoea ananatis* B1-9 and its efficient endophytic colonization capacity in plant tissues. The Plant Pathology Journal 28 (3): 270–281. <https://doi.org/10.5423/ppj.oa.02.2012.0026>
- Kumar A, Kumar A, Devi S, Patil S, Payal C, Negi S. 2012. Isolation, screening and characterization of bacteria from Rhizospheric soils for different plant growth promotion (PGP) activities: an in vitro study. Recent Research in Science and Technology 4 (1): 1–5.
- Li H, Qiu Y, Yao T, Ma Y, Zhang H, Yang X. 2020. Effects of PGPR microbial inoculants on the growth and soil properties of *Avena sativa*, *Medicago sativa*, and *Cucumis sativus* seedlings. Soil and Tillage Research 199: 104577. <https://doi.org/10.1016/j.still.2020.104577>
- Milošević NA, Marinković JB, Tintor BB. 2012. Mitigating abiotic stress in crop plants by microorganisms. Zbornik Matice Srpske za Prirodne Nauke 123: 17–26. <https://doi.org/10.2298/ZMSPN1223017M>
- Padmavathi T, Dikshit R, Seshagiri S. 2015. Effect of *Rhizophagus* spp. and plant growth-promoting *Acinetobacter junii* on *Solanum lycopersicum* and *Capsicum annuum*. Brazilian Journal of Botany 38 (2): 273–280. <https://doi.org/10.1007/s40415-015-0144-z>
- Palmer M, Steenkamp ET, Coetzee MPA, Avontuur JR, Chan WY, van Zyl E, Blom J, Venter SN. 2018. *Mixta* gen. nov., a new genus in the Erwiniaceae. International Journal of Systematic and Evolutionary Microbiology 68 (4): 1396–1407. <https://doi.org/10.1099/ijsem.0.002540>
- Queiroz Lopes M de F, Alves de Andrade FH, Torres da Silva R, Silva Lima LK, Alcântara Bruno R de L, Parente Nogueira AL da S. 2019. Chilli tolerance (*Capsicum annuum* L.) submitted to different concentrations of NaCl- of irrigation water. Idesia 37 (3): 75–80.
- Ruppel S, Franken P, Witzel K. 2013. Properties of the halophyte microbiome and their implications for plant salt tolerance. Functional Plant Biology 40 (9): 940–951. <https://doi.org/10.1071/fp12355>
- Saharan BS, Nehra V. 2011. Plant growth promoting rhizobacteria: a critical review. Life Sciences and Medicine Research 2011 (21): 1–30.
- Salazar-Jara FI, Juárez-López P. 2013. Requerimiento macronutricional en plantas de Chile (*Capsicum annuum* L.). Revista Bio Ciencias 2 (2): 27–34.
- Salazar-Ramírez MT, Sáenz-Mata J, Preciado-Rangel P, Fortis-Hernández M, Rueda-Puente EO, Yescas-Coronado P, Orozco-Vidal JA. 2021. Plant growth-promoting rhizobacteria associated to candelilla rhizosphere (*Euphorbia antisiphilitica*) and its effects on *Arabidopsis thaliana* seedlings. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 49 (2): 12294. <https://doi.org/10.15835/nbha49212294>
- Salusso FA, Plevich JO, Delgado ARS, Grosso LE, Ramos DF. 2015. Calidad de plántulas de lechuga en diferentes volúmenes de celdas y su influencia en el rendimiento. Revista Engenharia na Agricultura 23 (6): 575–583. <https://doi.org/10.13083/1414-3984/reveng.v23n6p575-583>
- Santamaría-César J, Figueroa-Viramontes U, Medina-Morales Ma. del C. 2004. Productividad de la alfalfa en condiciones de salinidad en el Distrito de Riego 017, Comarca Lagunera. Terra Latinoamericana 22 (3): 343–349.
- Sarduy DM, Díaz AI, Castellanos GL, Soto OR, Pérez RY. 2016. Sustratos y soluciones nutritivas para la obtención de plántulas de pimiento y su influencia en la producción en cultivos protegido. Centro Agrícola 43 (4):42-48.
- Shi Y, Lou K, Li C. 2011. Growth promotion effects of the endophyte *Acinetobacter johnsonii* strain 3-1 on sugar beet. Symbiosis 54 (3): 159–166. <https://doi.org/10.1007/s13199-011-0139-x>
- Vidigal DS, Dias DCF dos S, Dias LA dos S, Finger FL. 2011. Changes in seed quality during fruit maturation of sweet pepper. Scientia Agricola 68 (5): 535–539. <https://doi.org/10.1590/S0103-90162011000500004>